CRISPR Technology in Crop Improvement: Editing the Future of Food

Dr. P. V. Ramana Rao, Dr. V. Roja, Dr. N. Veronica and Dr. Y. Suneetha
Regional Agricultural Research Station, Maruteru, Acharya N. G. Ranga Agricultural University, Guntur, Andhra Pradesh.

Introduction

The world is racing against time. By 2050, a global population projected to exceed 9.7 billion people will demand nearly 70% more food than is currently produced while climate change simultaneously shrinks arable land, intensifies droughts, and accelerates the spread of crop diseases. Conventional plant breeding, though a cornerstone of agricultural progress for millennia, is simply too slow and imprecise to meet this unprecedented challenge alone. Enter CRISPR a molecular tool so elegant and powerful that it earned its inventors, Emmanuelle Charpentier and Jennifer Doudna, the Nobel Prize in Chemistry in 2020.

CRISPR, which stands for Clustered Regularly Interspaced Short Palindromic Repeats, is a natural bacterial immune system repurposed by scientists into a highly precise genome editing tool. Paired with the Cas9 protein which acts as a pair of molecular scissors CRISPR/Cas9 can locate a specific sequence in a plant's DNA and make targeted edits with unprecedented accuracy. Unlike conventional genetic modification (GMO), which involves inserting foreign DNA from another species, CRISPR often works entirely within the plant's own genome. This distinction is transforming regulatory landscapes and public perception worldwide. Over the last decade, CRISPR has moved rapidly from laboratory benches to farmers' fields, demonstrating tangible results across crops ranging from rice and wheat to tomatoes, bananas, and cassava. This article examines how CRISPR technology is reshaping crop improvement and what it means for farmers, food processors, and consumers.

How CRISPR/Cas9 Works in Plants

The mechanics of CRISPR/Cas9 are as intuitive as they are revolutionary. A short synthetic RNA molecule called a guide RNA (gRNA) is designed to match the target DNA sequence in the crop genome. This guide RNA escorts the Cas9 enzyme directly to the target site, where Cas9 makes a precise double-strand break in the DNA. The plant's own natural repair machinery then either disables the target gene (a process called gene knockout) or incorporates a desired new sequence (gene insertion or replacement).

The process can be completed in a fraction of the time required by conventional breeding weeks instead of years and without introducing foreign genetic material in many applications. This efficiency and versatility have made CRISPR the dominant genome editing tool in modern plant science (Peng et al., 2024).

Key Applications in Crop Improvement

Enhancing Yield

Increasing the yield potential of staple crops is the most immediate application of CRISPR in agriculture. In rice, CRISPR/Cas9 was used to target genes controlling grain size and number, resulting in measurable yield gains without compromising plant health (Kapoor et al., 2024). In maize, researchers replaced the native promoter of the *ARGOS8* gene with a constitutive promoter using CRISPR, creating varieties that show approximately 5% higher yield under drought conditions without any yield penalty under well-watered conditions (Kanth et al., 2025). These results, validated in field trials, represent a direct pathway to food security gains in stress-prone regions.

Improving Nutritional Quality

CRISPR is also being used to make crops more nutritious. In tomatoes, CRISPR/Cas9 editing dramatically increased the content of gamma-aminobutyric acid (GABA) a health-promoting compound linked to blood pressure reduction by up to 15-fold compared to conventional tomatoes (Kanth et al., 2025). In Japan, Sanatech Seed's CRISPR-edited *Sicilian Rouge* tomato with elevated GABA content was approved in 2021 and is already available to consumers making it one of the world's first commercialized CRISPR food products (University of Florida IFAS Extension, 2025). In rice, researchers used CRISPR to achieve a six-fold increase in beta-carotene, addressing Vitamin A deficiency a public health crisis affecting millions in South and Southeast Asia (Kanth et al., 2025).

Building Disease Resistance

Crop losses due to fungal, bacterial, and viral diseases cost the global economy billions of dollars annually. CRISPR is enabling the development of disease-resistant varieties without relying on chemical pesticides. A landmark example is the development of powdery mildew-resistant wheat by simultaneously editing three homologous copies of the *MLO* gene a feat impossible through conventional breeding due to wheat's complex hexaploid genome (Chen et al., 2024). In banana, CRISPR has been deployed to address Fusarium wilt (Panama disease), caused by *Fusarium oxysporum* f. sp. *cubense* Tropical Race 4 (TR4), which threatens to devastate the global Cavendish banana industry.

Tolerance to Abiotic Stress

Climate change-induced stresses drought, heat, salinity, and cold are among the most pressing threats to global food production. CRISPR/Cas9-mediated genome editing has been applied across several major crops to enhance tolerance to these stresses (Kapoor et al., 2024). In wheat and rice, editing of stress-responsive transcription factor genes has yielded varieties with improved survival under extreme heat and salinity traits of direct relevance to farming communities in South Asia, the Middle East, and Sub-Saharan Africa (PMC, 2025). A UK-based company (Alora, formerly Agrisea) secured field trial permits in 2023 for salt-tolerant CRISPR-edited rice a significant regulatory milestone for gene-edited crops in Europe.

Post-Harvest Quality and Shelf Life

For the food processing industry, CRISPR offers exciting tools to reduce post-harvest losses. Editing genes responsible for enzymatic browning and softening can extend the shelf life of fruits and vegetables significantly reducing waste and improving commercial value. In cassava, CRISPR/Cas9 editing of the *CYP79D1* gene substantially reduced toxic cyanogenic glycosides, enhancing the food safety of this critical staple crop for over 800 million people in Africa and Asia (Chen et al., 2024).

CRISPR vs. Conventional Breeding vs. GMO

Understanding where CRISPR fits within the spectrum of crop improvement technologies is essential for farmers, policymakers, and consumers alike.

Table 1: Comparison of Crop Improvement Approaches

Feature	**Conventional Breeding**	**GMO Technology**	**CRISPR/Cas9 Editing**
Time to develop variety	10–15 years	6–10 years	2–5 years
Precision of genetic change	Low (random recombination)	Moderate (targeted insertion)	High (precise editing)
Introduction of foreign DNA	No	Yes (transgenic)	Usually No
Regulatory classification	Non-regulated	Strictly regulated as GMO	Varies by country
Cost	Low	Very High	Moderate
Public acceptance	High	Low–Moderate	Moderate–High
Applicability to complex genomes	Limited	Moderate	High

Source: Adapted from Innovative Genomics Institute (2025); Kanth *(2025);* Kaur *(2025)*

CRISPR's key advantage is its precision combined with its non-transgenic nature in most applications. This positions it favourably with regulators and consumers who are cautious about traditional GMOs (Kanth et al., 2025).

Global Regulatory Landscape

The regulatory response to CRISPR crops has been anything but uniform. In the United States, the USDA does not regulate CRISPR-edited crops that could have been produced through conventional breeding a policy that has fast-tracked several products to market. Japan has taken a similarly progressive stance, approving CRISPR-edited products for consumer sale without requiring the same safety review process applied to GMOs. Argentina became the first country in the world to formally regulate gene-edited crops under a separate, lighter-touch framework in 2015, and has since approved several CRISPR products. China has aggressively embraced CRISPR in agriculture in early 2025, its Ministry of Agriculture granted approvals for three CRISPR-edited crop traits (improved soybean yield, herbicide-resistant wheat, and improved-quality rice) for nationwide cultivation through 2029. In contrast, the European Union has historically classified gene-edited crops under strict GMO regulations, though ongoing legislative reforms are moving toward a more science-based, differentiated approach.

In India, the Environment Protection Act and existing biosafety regulations currently classify genome-edited crops under the GMO framework, though ICAR and the Department of Biotechnology are actively working toward a CRISPR-specific regulatory pathway that distinguishes between transgenic and non-transgenic edits.

Challenges and Ethical Considerations

Despite its enormous promise, CRISPR technology in agriculture faces real and legitimate challenges:

- **Off-target edits:** Although rare with modern CRISPR tools, unintended changes in non-target genome regions remain a concern that requires rigorous screening before commercial release.
- **Delivery systems:** Introducing CRISPR components into plant cells especially in species with tough cell walls remains technically challenging for some crops
- **Intellectual property barriers:** CRISPR patents are concentrated in a small number of companies and universities, raising concerns about equitable access for developing countries and smallholder farmers.
- **Consumer acceptance:** Public trust in gene-edited food is still evolving, and transparent communication about the science and safety is essential.

- **Biodiversity concerns:** Large-scale deployment of a small number of edited elite varieties could reduce agrobiodiversity if not managed carefully within a broader crop improvement strategy

Conclusion

CRISPR/Cas9 technology represents one of the most transformative breakthroughs in the history of agriculture not because it replaces the wisdom of farmers and the complexity of ecosystems, but because it gives plant scientists an unprecedented degree of precision in working with the genetic blueprints of crops. From drought-tolerant maize and disease-resistant wheat to nutritionally enhanced rice and longer-lasting tomatoes, the applications of CRISPR in crop improvement are already delivering measurable benefits and the best results are arguably still ahead. For India, with its diverse agroclimatic zones, enormous smallholder farming sector, and growing food processing industry, CRISPR offers a powerful tool to address the twin imperatives of food security and agricultural sustainability. The path forward requires parallel investment in three areas: science (rigorous research and field validation), policy (clear, science-based regulatory frameworks that distinguish CRISPR from transgenic GMOs), and society (transparent public engagement that builds informed trust in gene-edited foods). As Charpentier and Doudna demonstrated, the future of food may lie in a microscopic molecular machine that has been quietly perfecting itself in bacteria for millions of years. The challenge now is to translate that molecular precision into meaningful, equitable, and sustainable gains for the farmers and communities who need it most.

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